ENERGY EFFICIENT CONGESTION CONTROL TECHNIQUES IN WIRELESS SENSOR NETWORKS

SYNOPSIS

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1. INTRODUCTION

Wireless Sensor Networks (WSN) play an important role in collecting data from a wide range of sources, especially those that are in accessible to people, and efficiently sending that data across different nodes. While each sensor node in a WSN has limited power and transmission capabilities, all nodes works together to send their sensed data towards the sink or to do some local coordination for data aggregation and the less information has to be transmitted. Army forces, agricultural, ecological forecasting, clinical surveillance, intelligent transportation, and home automation are some of the growing applications of WSNs. In WSNs, there are one or more sinks or Base Stations (BS) and many sensor nodes distributed over a wide area.

Typically, a sink node is a low-cost, user-friendly, battery-operated sensor network node with the ability to self-configure, manage node failure, and withstand challenging environmental conditions. Such nodes collect information by application type and transmit the data to the sink node. When many sensor nodes are actively sharing data, there is a potential that the network could get congested, which will lead to packet drops. There are two types of congestion in WSNs: link-level and node-level. Node level congestion causes buffer overflow when the packet interval exceeds the scheduled time, resulting in packet loss, maximizing queuing delays, and requiring packet re-transmission. Link level congestion occurs when multiple active sensor nodes within the same range attempt to transmit packets simultaneously. Therefore, when a packet is unable to reach the next hop, a collision will occur. In addition to increasing packet service times, this congestion can waste energy at the sensor node and reduce overall throughput and connection usage.

Congestion at the node and link levels may co-exist, which will have an immediate effect on the energy efficiency and network performance. Consequently, packet loss, unreliability, and lack of integrity ensue from congestion of data packets caused by densely placed nodes or high flow rates. Congestion which results in packet loss during communication has been a major issue in the field of WSN during the last few years. There is a chance that packet drop will occur when the network becomes congested due to a large number of sensor nodes that are actively transmitting data. Due to limited bandwidth, various types of data must be deal with varied priorities to avoid network congestion.

Congestion control is essential to avoid congestion and improve the network quality and performance immediately after congestion. The simplest way to avoid congestion is to stop sending packets into the network or slow down packet transmission rates. The congestion control mechanism monitors and detects congestion to conserve energy. It also requires that sensor nodes limit their flow to their next-hop neighbours and help them to deal with congestion. The congestion avoidance control loop starts as soon as the nodes receive the congestion notification, and the sensors are updated with the congestion mitigation choice to reduce network congestion.

The WSN controls the distribution rate change at each hop of the network. The main congestion management protocols include Congestion Detection and Avoidance (CODA) [1], Priority-based Congestion Management Protocol (PCCP) [2], Active Queue Management (AQM) [3], and Fairness Rate Control (FRC) [5]. Such protocols depend on the concept of priority, traffic load, and fair bandwidth utilization. According to the rate adjustment between nodes, a traffic class priority-based congestion mitigation protocol has been developed. According to the current congestion degree and the priority of the child nodes, the parent node dynamically computes and assigns the transmission rate for each of its child node. However, mitigating congestion by forwarding both Real-Time (RT) and Non-RT (NRT) packets is still challenging in WSN.

The main aim of this research work is to control the congestion in WSN by reducing the packet loss and increase in throughput. In this work, Proficient Rate Control algorithm (PRC) in which Weighted Priority Difference of Differential Rate Control (WPDDRC) with virtual queues is proposed to regulate the traffic in WSN. Then the PRC-FBA method for equitable bandwidth distribution, PRCDA-FBA approach with data aggregation mechanism to maximize the use of energy across all participating nodes and EPRCDA-FBA to reduce energy consumption at highly energy-constrained nodes are proposed.

2. LITERATURE SURVEY

Swain et al. [11] proposed a pair of rate control algorithms to combat congestion and keep transmission losses to a minimum. Using the rate controls higher-order differentials packet loss is automatically reduced while throughput is maximized. The concept of weighted prioritization has only served to strengthen this. The rate control method was created to increase throughput while decreasing delay and loss, therefore preventing network congestion.

Subha Kanta et.,al, [8] proposed Two rate control algorithms: Difference of Differential Rate Control (DDRC) and Weighted Priority Difference of Differential Rate Control (WPDDRC). Using this method, low packet delay, less energy consumption, and high Packet delivery ratio. Then the rate control method had the low battery energy, bandwidth, processing capability, and finite memory capacity.

Sarode et al., [9] developed Data Transmission Protocol Based on Priority Approach (DTP-PA) for data transfer at a varying reporting rate in a sink-specified decision time. Packet scheduling based on packet priority and hop count are two additional methods that have been developed with networked traffic initially. A pricing adjustment was also made based on the buffer's current occupancy. But it disregards the queuing model at individual network nodes.

Jasim et al.[4] developed a Secure and Energy-Efficient Data Aggregation (SEEDA) protocol which was secure and energy-efficient data aggregation for WSN using an access control model. The proposed protocol enhances the authentication of MAC by generating a random value and random timestamp with a secret key. The base station node verifies the fake aggregated data before sending it to the server. Other than that, the proposed protocol detects and prevents attacks such as Sybil and sinkhole. The base station nodes also utilize the distance and timestamp between nodes to avoid delay in the network.

Srivastava et al.,[10] proposed a rate-based congestion control method that is cluster routing - dependent to cut power consumption in WSN. The nodes were initially categorized using a combination of K-means and Greedy best-first search. The firefly optimization was then used to implement the rate control method, speeding up the pace at which packets were sent. The information was also transmitted via a routing scheme inspired by the optimization techniques used by ant colonies. However, it does not converge quickly, therefore the time required to do so was considerable.

Yadav et al. [13] developed an Efficient Congestion Avoidance protocol using Huffman coding and Ant colony optimization (ECA-HA) to enhance network efficiency. According to the link energy, packet loss ratio, and congestion level, ant colony optimization uses to find several alternate routes with minimal congestion. Then, the Huffman coding utilized the packet loss rate on these alternative routes to select the best way. But, it was not suitable for ample search space since the network increases quickly.

Pan et al. [6] developed an adaptive congestion window of Bottleneck Bandwidth and Round-trip (BBR) propagation time, which regulates the congestion window gain of all BBR flows in the network load. By controlling the top of the congestion window based on the packet delivery ratio and queue status, this method avoided the Round Trip Time (RTT) fairness issue. But, it needs to choose the proper congestion window gain values since the scaling factor needs data support in real-time WSN.

Aimtongkham et al. [1] developed a new routing scheme that reduces congestion. At first, the multistage fuzzy logic defined an optimal notification level for queue control. The congestion notification controlled by the weights obtained from the metrics related to congestion, reducing the likelihood of transmission loss. But, it was not applicable for heterogeneous traffic data transmission.

Yan and Qi [14] developed a Congestion-Aware Routing Algorithm (CARA) for unlimited-lifespan WSNs by integrating the geographic distance and traffic load of sensor nodes. Based on the geographic distance, four different decision parameters, such as node load factor transmit rate, cache remaining rate, and forward mean cache remaining rate, were defined to select the optimal node as the next hop. But, it did not consider the power and energy factors influencing the network lifespan in real-time scenarios.

Grover et al [3] proposed novel Rate Aware Congestion Control (RACC) technique to divide network congestion into three types. User Datagram Protocol (UDP back) pressure technique helped RACC lower its bandwidth needs, which in turn lowers the number of headers/packets that need to be processed and in turn, the amount of power needed to do so. Some of the more common approaches for controlling data transmission rates in WSN.

3. PROBLEM STATEMENT

Queue over flow is one of the constraints which is responsible for the packet loss in the network. The rate control at a given sensor node with the combination of priority assignment of traffic class, fair distribution of bandwidth is not sufficient to control the congestion under all circumstances and hence queue management is essential for an energy efficient rate control scheme.

4. OBJECTIVES OF THE RESEARCH

- To reduce the packet loss by virtual queue management.

- To maximize the bandwidth utility function in WSN.
- To predict the nodes and control the packet retransmission by using the data aggregation technique.
- To evaluate the QoS standards in terms of data transmission rate adjustment, reduce energy consumption of the nodes and increase network life time.

5. RESEARCH METHODOLOGIES

5.1 Energy-aware Proficient Control Scheme for Congestion Control in WSN

The large queue can occasionally fill up more than half the buffer, leading to considerable packet loss and delay, a Proficient Rate Control (PRC) method is proposed using Weighted Priority Difference of Differential Rate Control (WPDDRC) with a priority-based queuing system. With the PRC algorithm, the incoming packets from each child node are accumulated in one of two virtual queues on a single physical queue: one for low-priority traffic and another for high-priority traffic. Congestion in the virtual queue is detected when a packet is successfully received, and the PRC responds by adjusting the child's transmission rate. By considering the relative importance of each type of traffic and the current queue status, this PRC method has the potential to mitigate the negative effects of congestion and buffer overflow in WSN.

5.2 Congestion Handling in WSN using PRC-FBA Techniques

In the second phase of the research work, a PRC with Fair bandwidth Allocation (PRC-FBA) protocol proposed by considering both traffic type priority and fair bandwidth assignment. The Signal-to-Noise plus Interference Ratio (SINR) model was initially used to examine the problem of bandwidth assignment in WSNs. This model seeks to find a trade-off between fairness and network efficiency. Then, a novel bandwidth utility factor is given for fairness and efficiency. Also, an approximate solution is provided by mutually computing the node relationship and time slot assignment. In addition, the problem is divided into two smaller problems and expressed as a non-linear system. In the two methods, The nodes association is computed in the first phase, and time slots are assigned in the second step to maximize the utility factor. In WSNs, it accomplishes a fair bandwidth assignment and boosts network efficiency.

5.3 Proficient Rate Control with Data Aggregation and Fair Bandwidth Allocation Algorithm

PRCDA-FBA is an aggregation method that makes use of a powerful data aggregation mechanism to maximize the equitable consumption of battery life across all involved nodes, and it is the result of the third phase of study. Through the use of priority-based rate network coding and data aggregation, network throughput can be increased while Simulation times for data transmission and energy consumption are both decreased. Random Linear Network Coding is used to generate network coding (RLNC). The transmission frequency of a node is equal to the number of data packets it sends in one communication round. Sensor nodes should ideally only transmit a single packet every communication cycle. Reduced transmission frequency, on the other hand, increased network channel capacity, which enhanced overall network throughput. The network coding path combines data for transmission to the next hop, increasing channel usage and reducing packet redundancy in the network. When congestion occurs, an adaptive methodology is triggered in which node transmits data by combining using network coding to decrease packet dropping rate. With priority based Network coding, the parent node decides whether or not to activate networking coding depending on packet priority, node residual energy, and latency.

Bandwidth allocation in PRCDA-FBA is also improved by long short-term memory (LSTM) recurrent neural networks, which can learn long-term dependencies. They have a temporal dimension that allows them to discern patterns in data sequences. This task necessitates learning novel network behaviors while keeping track of historical data, therefore this property is of special relevance. The bandwidth utilized in the past events with parameters like packet drop rate, energy, priority of packets and delay of packets are used to predict the future bandwidth requirements of path.

5.4 Enhanced Proficient Rate Control with Data Aggregation and Fair Bandwidth Allocation Algorithm

In the fourth phase of research work, EPRCDA-FBA is proposed to further save energy utilization and improve network life time. The major purpose of this work to ensure that QoS standards are met in terms of delayed data delivery, reduced energy consumption of energy-intensive nodes, and increased network lifespan. This protocol's priority-based technique of regulating data transfer rates takes into consideration the node's spare processing capacity. To start, a prediction model is utilized to figure out how much of a graph in node transmit power can be tolerated without significantly impacting the packet delivery ratio. Then, to avoid overhearing energy-critical nodes, a priority of nodes for delivering traffic

classes of packets is determined using a combination of energy. The nodes employ this prediction model for two objectives. First, a node can use this model to determine how much power it can lower in relation to a receiver while keeping a specific level of connection quality. Second, the node can determine how much overhearing is transmitted to the energy essential neighbors at a given transmit power level. Even while overhearing is typically a concern at the physical layer, it can be estimated at the network layer by counting the number of received packets. Since the broadcaster's power level is a crucial component in defining the link quality between a pair of nodes, a prediction model is constructed at the receiver end to establish a correlation between the broadcast power level at the emitter and the forward network lifetime at the receiver. As a result, this protocol effectively avoids the slowdown of a network.

6. SIMULATION RESULTS

The effectiveness of the PRC, PRC-FBA, PRCDA-FBA, and EPRCDA-FBA algorithm is assessed by simulating them in Network Simulator version 2.35 (NS2.35). Additionally, their efficiencies are compared with the existing algorithm, such as DDRC and WPDDRC algorithms in terms of different network metrics. The parameters setup for simulation is given in Table 1.

Table 1. Simulation Parameters

Parameter	Range
Simulation area	1000×1000m
Number of nodes	900
MAC layer	IEEE802.11
Communication range	300m
Traffic source	CBR
Number of traffic categories	4
Packet size	200bytes
Data rate	2Mbps
Transmission power	285.63mW
Operating frequency	5GHz
Routing protocol	AODV
Mobility model	Random walk
Mobility Speed	10m/s
Simulation time	120sec

The network metrics used for analysis are defined as the following:

- Throughput: The proportion of the number of packets the target node receives within a unit.

$$Throughput = \frac{Total\ number\ of\ packets\ received}{Time} \quad (1)$$

- Packet loss is the proportion of the number of packets lost during transmission.

$$Packet\ Loss = \frac{Number\ of\ dropped\ packets}{Number\ of\ received\ packets + number\ of\ dropped\ packets} \quad (2)$$

- End-to-end (E2E) delay: It is the time taken for a packet to be sent from a source node to the sink.

$$\mathrm{E2EDelay} = \mathrm{Time}_{\mathrm{sink}} - \mathrm{Time}_{\mathrm{source}} \quad (3)$$

Where, $\mathrm{Time}_{\mathrm{sink}}$ is the time at the sink while receiving the packet and $\mathrm{Time}_{\mathrm{source}}$ is the time at the source node while transmitting that packet.

- Queue size: It is the number of packets in the queue.
- Data transmission rate adjustment: The data transfer rate of origin, which handles the congestion and buffer overflow in WSN.

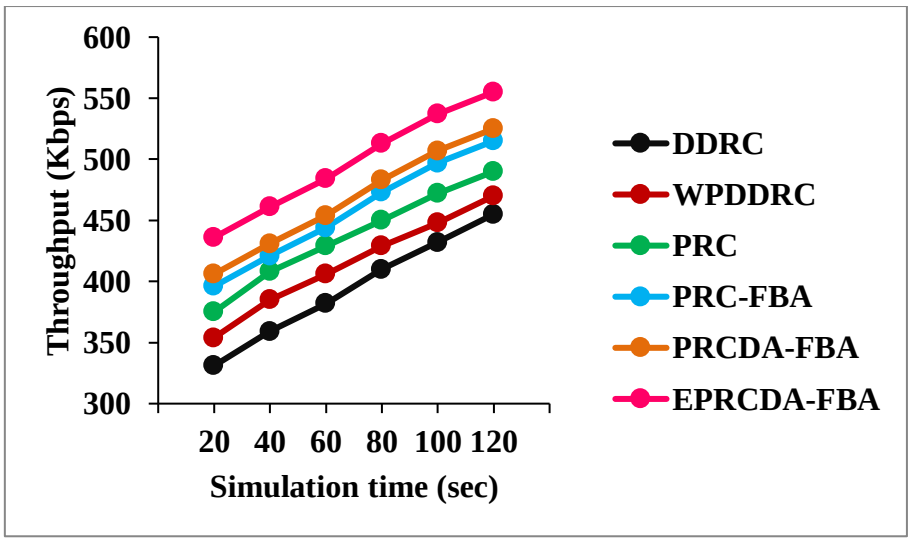

Figure 1. Throughput vs. Simulation Time

Figure 1 shows the throughput values (in Kbps) for different proposed and existing congestion control algorithm under a varying simulation time (in a sec). It is observed that the EPRCDA-FBA algorithm attains a higher throughput compared to the other protocols while increasing the simulation time significantly. That is, the throughput of the EPRCDA-FBA for simulating 120sec is 21.98% greater than the DDRC, 18.09% greater than the WPDDRC,

13.27% greater than the PRC, 7.77% greater than the PRC-FBA and 5.71% greater than the PRCDA-FBA protocols. This is because of handling the priority levels of traffic classes at virtual queues in the nodes and Assigning fair bandwidth for each node in the network.

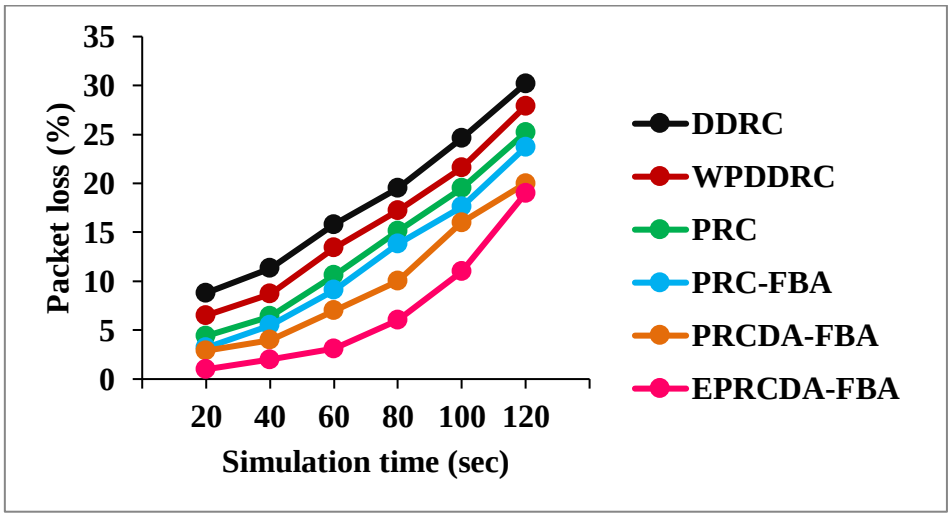

Figure 2. Packet Loss vs. Simulation Time

Figure 2 shows the packet loss (in %) for different proposed and existing congestion control algorithms are under varying simulation times (in a sec). It was noticed that the EPRCDA-FBA attains a lower packet loss than all other algorithms when the simulation time increases. That is, the packet loss of the EPRCDA-FBA for simulating 120sec is 37.09% less than the DDRC, 31.9% less than the WPDDRC, 24.6% less than the PRC, 19.83% less than the PRC-FBA and 5% less than the PRCDA-FBA algorithm. This is owing to virtual queues and sharing an adequate bandwidth for each node. Also, effective data aggregation prevents packet loss during transmission, which in turn causes higher network throughput.

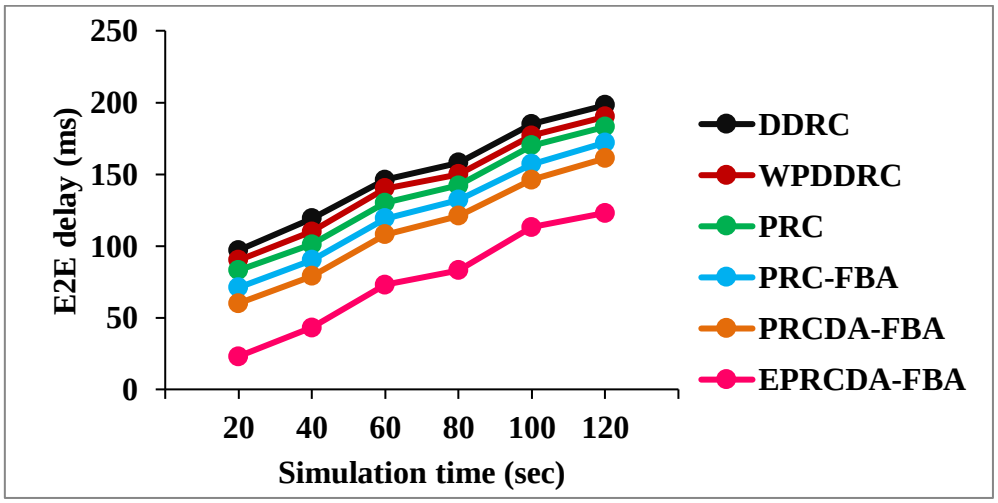

Figure 3 E2E Delay vs. Simulation Time

Figure 3 shows the E2E delay (in ms) for different proposed and existing congestion control protocols under varying simulation times (in a sec). It noticed that the EPRCDA-FBA protocol attains a minimum E2E delay compared to all other protocols when increasing the simulation time. That is, the E2E delay of the EPRCDA-FBA for simulating 120sec is 37.88% less than the DDRC, 35.26% less than the WPDDRC, 32.79% less than the PRC, 28.49% less than the PRC-FBA and 23.6% less than the PRCDA-FBA protocols. Therefore, it relates to the maximum throughput and the minimum packet loss.

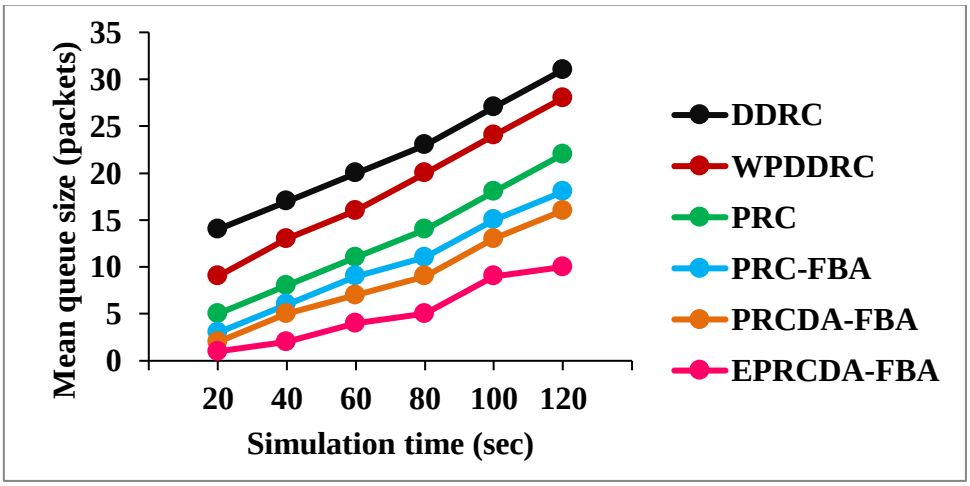

Figure 4. Mean Queue Size vs. Simulation Time

Figure 4 shows the mean queue size (in the number of packets) for different under a varying simulation time (in a sec). It is observed that the EPRCDA-FBA algorithm reduces the average queue length, called mean queue size, compared to all other algorithm when increasing the simulation time. That is, the mean queue size of the EPRCDA-FBA for 120sec is 67.74% less than the DDRC, 64.29% less than the WPDDRC, 54.55% less than the PRC, 44.44% less than the PRC-FBA and 37.5% less than the PRCDA-FBA algorithm. This is because of adequately handling the traffic classes based on their priorities, stabilizing the queue length around a required range.

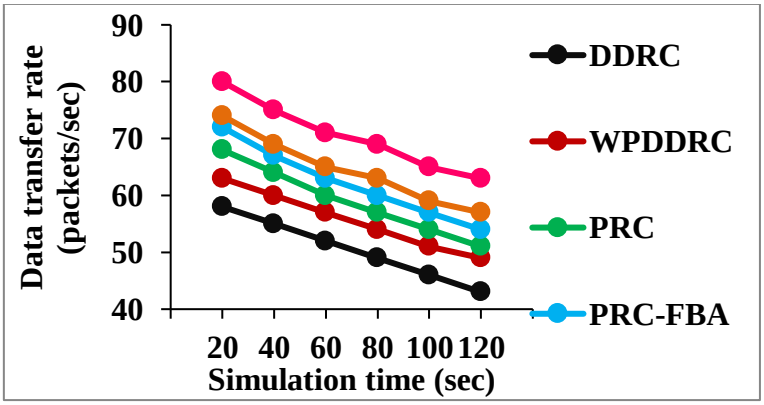

Figure 5. Data Transfer Rate vs. Simulation Time

Figure 5 illustrates the data transfer rate (in packets/sec) for different proposed and existing congestion control algorithm under varying simulation times (in a sec). It indicates that the EPRCDA-FBA algorithm can increase the data transfer rate by distributing the adequate bandwidth and adjusting the transfer rate efficiently compared to all other protocols when increasing the simulation time. That is, the data transfer rate of the EPRCDA-FBA for simulating 120sec is 46.51% higher than the DDRC, 28.57% higher than the WPDDRC, 23.53% higher than the PRC, 16.67% higher than the PRC-FBA and 10.53% higher than the PRCDA-FBA protocols. This protocol is because of adequately handling the traffic classes based on their priorities, stabilizing the queue length around a required range. Hence, the EPRCDA-FBA can transfer the highest priority traffic classes without congestion by allocating a reasonable data transfer rate.

7. CONCLUSION

This research proposed algorithms to enhance the network throughput and reduce packet loss by alleviating the congestion on the WSN. Initially, the PRC algorithm was proposed to control the congestion and buffer overflow on the WSN by considering both traffic class priority and queue status. Then, the PRC-FBA algorithm was designed to allocate an adequate bandwidth and increase the network utility in WSN. Additionally, the PRCDA-FBA algorithm was proposed to aggregate the data from all participating nodes by applying the RLNC and predicting the bandwidth requirements using LSTM to increase the overall network throughput with reduced energy utilization. Further, the EPRCDA-FBA algorithm was designed to prevent overhearing at energy-critical sensor nodes and improve the network life span. Finally, the simulation outcomes proved that the EPRCDA-FBA-based congestion control algorithm has a mean throughput of 497.67Kbps, a mean packet loss of 7.02%, a mean E2E delay of 76.33ms, all the mean queue size of 5 packets, and a data transfer rate of 71 packets/sec compared to the all other congestion control algorithm in WSN.

8. ORGANIZATION OF THE THESIS

The thesis contents are organized as follows:

Chapter 1 discusses about the overview of WSN, its characteristics, congestion in WSNs and the Congestion control mechanism.

Chapter 2 a brief review of the congestion control technique in wireless sensor network is done. From the study, the key challenges are identified.

Chapter 3 presents the algorithms and the metrics used for evaluating the performances

Chapter 4 explains the first objective of PRC algorithm and its derivation towards the congestion avoidance in WSN.

Chapter 5 describes the second goal of the study, PRC-FBA, and how it is used to address the bandwidth allocation issue.

Chapter 6 describes the third objective of the study, PRCDA-FBA, and the implementation module that is used to improve the power of each node.

Chapter 7 describes the fourth objective of the research EPRCDA-FBA and its description for preventing the degradation of network performance.

Chapter 8 concludes with a summary of the findings and discusses the improvements to be made in the future.

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1. Vanitha, G., Amudha. P, (2023). "Quality of Service aware Dynamic Bandwidth Allocation for Rate Control in WSN", International Journal on Recent Trends in Computing and Communication" ISSN: 2321-8169 Volume: 11 Issue: 11s. (Scopus).
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2. Analysis of Algorithms to Control the Congestion by Improve Energy Efficiency in WSN, International Conference on Technologies for Smart Green Connected Societies on 29.11.2021 to 30.11.2021 Organized by SPAST Foundation and Associated Partner Institutions (online).
3. Energy-Aware Proficient Control Scheme for Congestion Control in WSN, International e-Conference on information, Communication and Networking (eICICN-2021) on 9.4.2021 and 10.4.2021, Organized by Easwari Engineering College, Chennai.